INSTRUCTION MANUAL

MODEL 515

MEGOHM BRIDGE

WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof (except tubes and batteries) which, within a year after shipment, proves defective upon examination. We will pay domestic surface freight costs.

To exercise this warranty, call your local field representative or the factory, DDD 216-795-2666. You will be given assistance and shipping instructions.

REPAIRS AND RECALIBRATION

Keithley Instruments maintains a complete repair service and standards laboratory in Cleveland, and has an authorized field repair facility in Los Angeles.

To insure prompt repair or recalibration service, please contact your local field representative or the plant directly before returning the instrument.

Estimates for repairs, normal recalibrations, and calibrations traceable to the National Bureau of Standards are available upon request.

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*Yellow Change Notice sheet is included only for instrument modifications affecting the Instruction Manual.

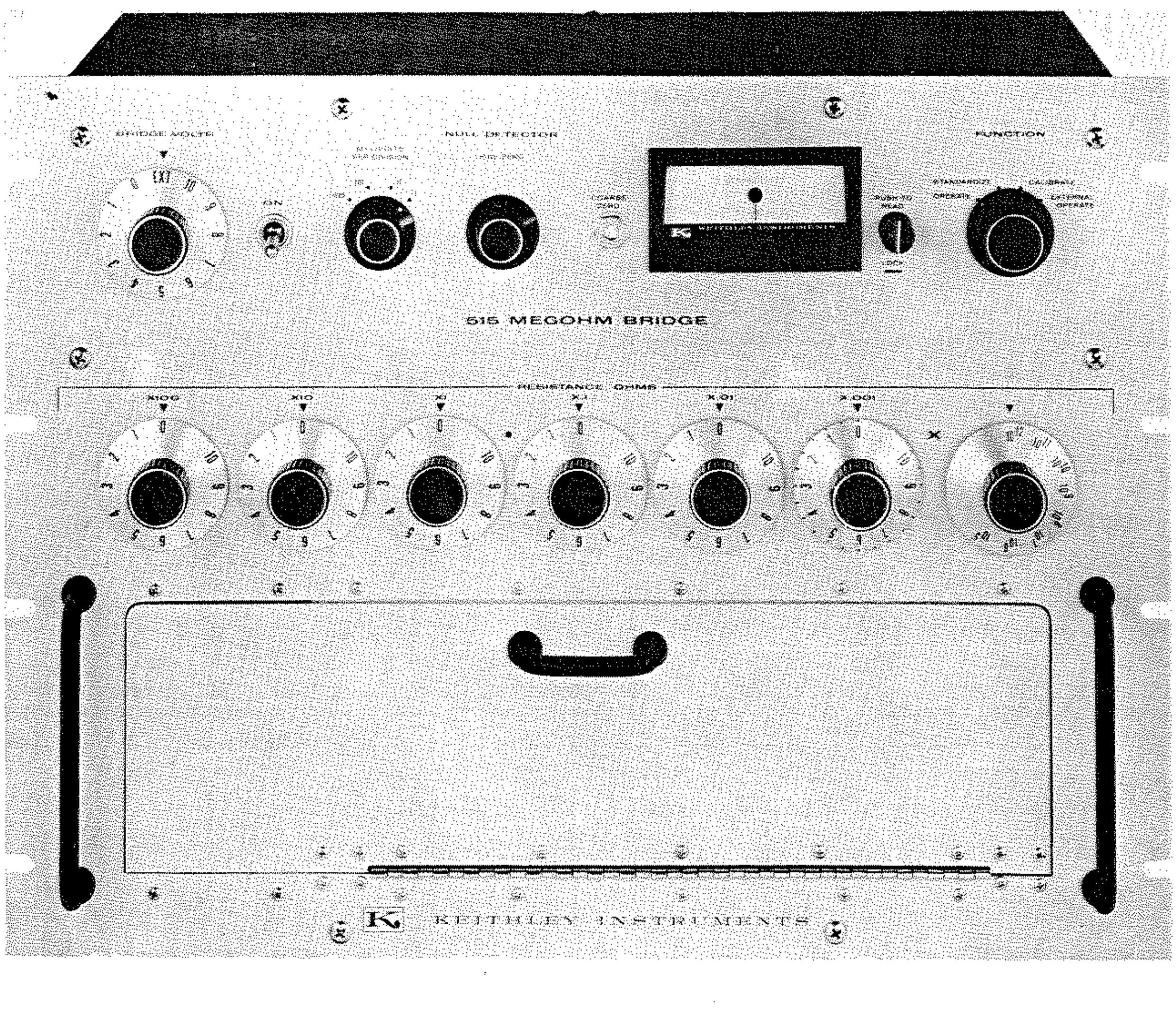
SECTION I - INTRODUCTION

The Model 515 Megohm Bridge is a Wheatstone Bridge for measuring resistors from 10^5 ohms to 10^{15} ohms with accuracies from 0.05% to 1.0%. It is complete, with an electrometer null detector, shielded enclosure for the unknown, and a bridge voltage supply.

A unique system of switches is provided to allow corrections to be made for the slow changes in resistance of the standard high megohm resistors. This enables all values of resistance to be read with rated accuracy, directly from the bridge dials.

Bridge voltages in one volt steps up to 10 volts are available from the internal supply. With external supplies, voltages as high as 1,000 volts can be used.

A connector is provided so that unknown resistors can be measured outside the instrument as well as in the built-in shielded enclosure.



SECTION II - SPECIFICATIONS

RANGE: 10^5 to 10^{15} ohms with a six-dial in-line readout.

ACCURACY: As tabulated below, if bridge is operated so that voltage across standard resistor does not exceed 10 volts.

Range Ohms	Accuracy	Possible Bridge Voltage	Min. Volt. for Rated Accuracy
10^5 to 10^7	0.05%	1 to 1000 V	5 V
10^7 to 10^8	0.05	1 to 1000	50
10^8 to 10^9	0.10	1 to 1000	3
10^9 to 10^{10}	0.15	1 to 1000	2
10^{10} to 10^{11}	0.2	1 to 1000	1
10^{11} to 10^{12}	0.25	1 to 1000	1
10^{12} to 10^{13}	0.30	1 to 1000	1
10^{13} to 10^{14}	0.5	1 to 1000	10
10^{14} to 10^{15}	1.0	10 to 1000	100

For less than minimum voltage, accuracy decreases in proportion to the ratio of applied voltage to minimum stated voltage.

INPUT: Built-in compartment or Remote Test Chamber with teflon-insulated triaxial cable.

GROUNDING: One terminal of unknown is at ground potential.

NULL DETECTOR: Electrometer with a grid current of less than 5 x 10^{-14} amperes and sensitivity ranges of 1 volt per div. to 1 millivolt per div. in decade ranges. Reading is non-linear past 1/3 of full scale for ease in balancing.

ZERO CHECK: Normally closed zero-check button shorts out null detector input except when depressed.

BRIDGE POTENTIAL: Internal: From zero to 10 volts in one volt steps selectable from the front panel. External: With Keithley Model 240 or 241 Power Supply, from zero to 100 volts on any resistance reading, from 100 to 1000 volts provided the readout dial is at least in the x10 position. Bridge interlocks, and the inherent overload protection of the Keithley power supplies, prevent damage if readout dial is inadvertently placed in the wrong position. Since other types of power supplies do not provide the correct overload protection, only the Keithley Model 240 or 241 is recommended.

POWER: 100-130 or 200-260 volts, 50-60 cps. 10 watts.

TUBE AND TRANSISTOR COMPLEMENT: 1-5886, 2-6418, 1-OB2; 1-2N1535, 6-2N1381.

ACCESSORIES AVAILABLE: Model 5151 End Frames with mounting hardware, rubber feet. Model 5154 Cabinet; Model 5152 Remote Test Chamber with 60" triaxial cable and bridge connector; Model 5153 60" triaxial cable with bridge connector on one end.

DIMENSIONS: Model 515 Megohm Bridge, 19" w x 14" h x $10\frac{1}{4}$" d. Model 5154 Cabinet, 21" w x 25" h x $16\frac{1}{2}$" d.

NET WEIGHT: Model 515 Megohm Bridge, 24 lbs. Model 5154 Cabinet, 52 lbs.

SECTION III - OPERATION

A. OUTLINE OF PROCEDURE, (taken from instructions fastened to the inside of the door of the Shielded Measuring Compartment).

1. Connect power cord to 115 volts, 50/60 cps unless specified on rear for 230 volt. To change line voltage see Section V - Maintenance.

2. Turn on power; set MILLIVOLTS PER DIVISION switch to 1000; release PUSH TO READ switch. Set meter to zero with FINE ZERO. If necessary use COARSE ZERO. Increase sensitivity and rebalance. Drift which may be apparent at maximum sensitivity will become negligible after a short warm-up.

3. STANDARDIZING: Set FUNCTION switch to STANDARDIZE: MULTIPLIER dial to 10^6; and RESISTANCE, OHMS dials to 10.000. Bring to exact null with OHMS dials; at the same time increase the null detector sensitivity to maximum. Release PUSH TO READ button and set FUNCTION switch to CALIBRATE. Adjust 10^6 CALIBRATE potentiometer to give a null when PUSH TO READ switch is operated. Next set exponent dial to 10^7 and repeat step 3. Do the same in sequence up thru 10^{11}. This completes the bridge standardization.

4. OPERATION: Place resistor to be measured in compartment. Locate the ground clip to suit the resistor length, and close compartment.

Select bridge voltage. Internal voltages from 1 to 10 volts or external voltages up to 100 volts may be used with no special precautions. Above 100 volts the x10 or x100 dial must not be set at zero. With the Keithley 240 or 241 Power Supply, the interlock circuit will prevent damage.

Set null detector sensitivity to minimum and operate PUSH TO READ button. If null detector deflects to left the readout dials (RESISTANCE, OHMS) are set below value of resistance. Increase the indicated RESISTANCE until a null is obtained. If null detector deflects to right reduce the indicated RESISTANCE. If no deflection is observed increase null detector sensitivity. Final balance should be made with enough sensitivity to give required accuracy.

For external operation, attach special cable only to input connector and set FUNCTION switch to EXTERNAL OPERATE. Since the door interlock is now inoperative observe care with high bridge voltages.

5. ACCURACY: As tabulated below, if bridge is operated so that voltage across standard resistor does not exceed 10 volts.

Range, Ohms	Accuracy	Possible Bridge Voltage	Min. Volt. for Rated Accuracy
10^5 to 10^7	0.05%	1 to 1000 V	5 V
10^7 to 10^8	0.05	10 to 1000	50
10^8 to 10^9	0.10	1 to 1000	3
10^9 to 10^{10}	0.15	1 to 1000	2
10^{10} to 10^{11}	0.2	1 to 1000	1
10^{11} to 10^{12}	0.25	1 to 1000	1
10^{12} to 10^{13}	0.30	1 to 1000	1
10^{13} to 10^{14}	0.5	1 to 1000	10
10^{14} to 10^{15}	1.0	10 to 1000	100

For less than minimum voltage, accuracy decreases in proportion to the ratio of applied voltage to minimum stated voltage.

B. DESCRIPTION OF CONTROLS AND TERMINALS:

BRIDGE VOLTS: This rotary switch adjusts the voltage applied to the bridge in 1 volt steps up to 10 volts and also is used to energize the external supply circuit when it is in the EXT position.

ON: Toggle switch is the main power switch. Presence of power is indicated by the illuminated meter dial.

MILLIVOLTS PER DIVISION: Rotary switch provides decade steps of null detector sensitivity.

FINE ZERO: Ten-turn control is used for setting the null detector to zero.

COARSE ZERO: Eleven position rotary switch sets the meter zero within the range of the FINE ZERO controls. It may be switched with a screwdriver from the front panel.

NULL INDICATOR: Three-inch meter, incorporating a non-linear movement for easy bridge balancing.

PUSH TO READ: Push-button switch normally shorts the null detector input. It may be locked in the open position.

FUNCTION: Four position rotary switch provides the necessary circuit arrangements for calibration of the standards, and also employed when the unknown resistor is outside the instrument.

RESISTANCE, OHMS: These seven dials include five decade step switches and one rheostat which form the variable arm of the bridge. The seventh dial is a multiplier switch. At balance, the unknown resistance is read directly from these dials.

Below these dials is the shielded test chamber. This contains the external input connector and six calibration controls in addition to the guarded test terminal. The external input connector is a teflon insulated triaxial receptacle (Gremar 5632A).

FUSE: A fuse extractor post is located on the rear of the instrument. For 115 volt operation use a 3 AG, $\frac{1}{4}$ amp. fuse; for 230 volts use a 3 AG, 1/8 amp.

POWER CORD: The three wire cord with the NEMA approved three-prong plug provides a ground connection for the cabinet. An adapter to allow operation from two prong outlets is provided.

ACCESSORY OUTLET: A three-terminal convenience outlet is provided on the rear for operation of an external power supply. It is wired directly to the power cord and is not controlled by the bridge power switch.

EXTERNAL INPUT: UHF receptacle on the rear of the instrument, used to connect an external power supply when bridge voltages above 10 volts are desired.

C. OPERATION STEPS

1. Connect power cord to 115 volt, 50/60 cps, unless specified on rear for 230 volts. To change line voltage see Section V, Maintenance.

2. Set null detector to 1000 millivolts per division and unlock PUSH TO READ switch so null detector input is shorted (note the null detector is normally shorted corresponding to an open galvanometer key).

3. Turn power on and allow 30 seconds for warm-up. The meter should indicate zero. Increase null sensitivity and re-zero if necessary. If the detector cannot be set to zero, use the coarse zero control.

4. Standardize the bridge if necessary (See D - Standardization, following).

5. Insert the component to be measured in its test fixture. Set the function switch to OPERATE when using the self-contained shielded measuring compartment, or set it to EXTERNAL OPERATE when the unknown is located in the Model 5152 Remote Test Chamber or in another external sample holder. See E. Connecting to the Unknown Resistor, which follows for detailed instructions for connecting the unknown.

6. Set the BRIDGE VOLTS to the desired value. For external bridge supplies, see F. External Bridge Voltage Supply following.

7. Operate the PUSH TO READ button and balance for null with the resistance dials. Increase the null detector sensitivity (See H. Accuracy) to give the desired accuracy at final balance. The resistance of the component is then read directly from the resistance dials.

Use x 10 to x 0.001 dials for resistors to 10^{14} and all dials for resistors from 10^{14} to 10^{15}.

D. STANDARDIZATION

Wire-wound resistors have the greatest accuracy and keep their calibrations over long periods of time. Values greater than about one-megohm, however, are too large and too expensive to be widely used. Carbon film resistors provide values up to 10^{12} ohms and higher with reasonable success and this type resistor is used in the Model 515. But the value of these resistors changes with time, sometimes one or two percent per year.

The Keithley Model 515 Megohm Bridge has been designed so that frequent compensations can be made for variations of its high-megohm standard resistors. This process is called Standardization and is carried out as given below. Section IV - Circuit Description discusses the circuitry involved.

The bridge should be restandardized following a change in temperature of greater than about 10°F, and at least once each week, to compensate for the errors introduced in the carbon standards by temperature and time. For the utmost accuracy possible from the bridge, it can be standardized daily, hourly, or immediately before a critical measurement.

To Standardize the Bridge:

1. Set the Multiplier (the farthest right of the RESISTANCE, OHMS dials) to 10^6.

2. Set FUNCTION switch to STANDARDIZE

3. Set NULL DETECTOR to 1000 mv per division.

4. Operate PUSH TO READ switch and balance the bridge as in normal operation. The reading will be close to 10.00. The final balance should be made with maximum null sensitivity.

5. Release PUSH TO READ switch and set FUNCTION switch to CALIBRATE.

6. Operate PUSH TO READ switch and re-balance the bridge with the 10^6 CALIBRATE potentiometer located in the Shielded Measuring Compartment.

7. Turn FUNCTION switch back to STANDARDIZE.

8. Turn multiplier to 10^7 and repeat steps 4 thru 7. Do this for each successive multiplier thru 10^{11}. The 10^{12} position is not used since the 10^{12} ohm standard is calibrated in the 10^{11} multiplier position.

E. CONNECTING THE UNKNOWN RESISTOR

1. Using Internal Test Chamber

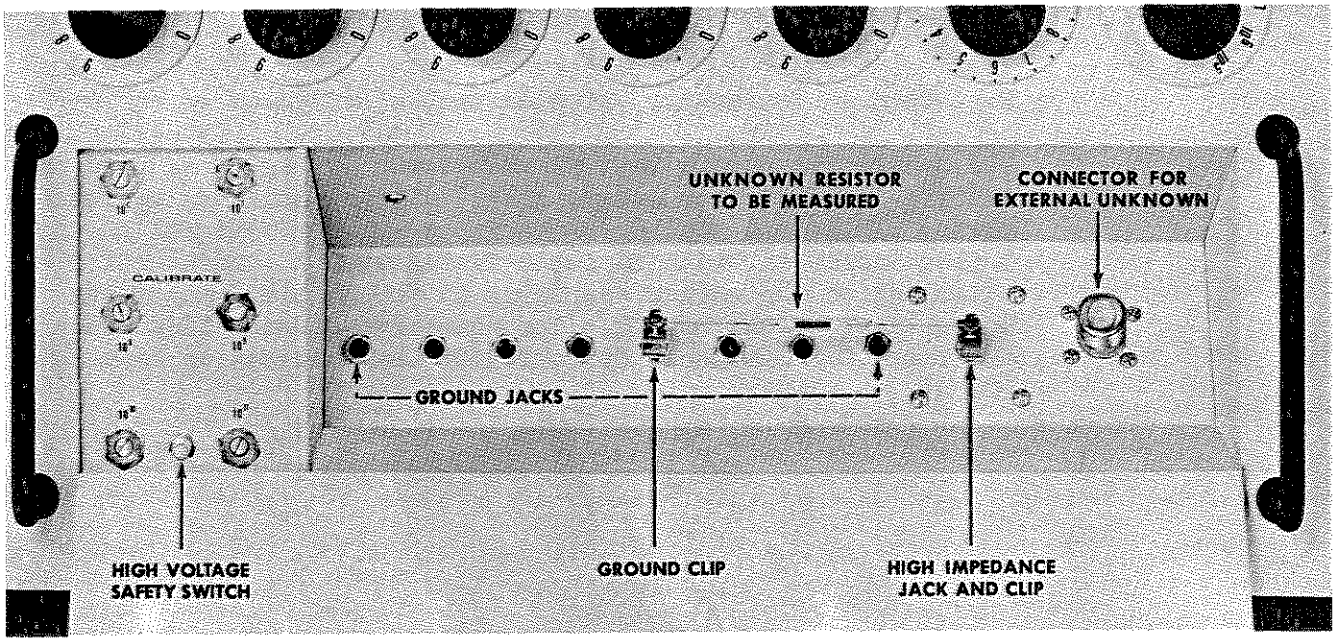


Fig. 1 Shielded Measuring Compartment, With Unknown Installed

The bottom section of the bridge contains the shielded compartment for holding the unknown resistor, and is accessible when the hinged door has been opened. The compartment has been designed for greatest user convenience. Its being shielded eliminates troublesome pickup, and the unit construction eliminates the necessity for having cables running from the unknown to the bridge, with their associated flexure noise.

The measuring compartment will accept resistors up to about eight inches long. Connections to the bridge are made through banana jacks. A convenient clip to use with the banana jack is the readily available Grayhill Test Clip #2-1; it has a banana plug on the bottom and spring clips on the top for holding the resistor heads; three are supplied with each bridge. These clips are illustrated in Fig. 1, holding a typical high-megohm resistor.

A number of ground jacks have been provided so that the ground clip can readily be placed for conveniently holding the unknown resistor, irrespective of its length.

In measuring high resistances, the many precautions necessary in electrometer techniques must be borne in mind; most important are the need for dryness and cleanliness so that leakage resistance paths from the HI terminal to ground will not affect the accuracy of measurement, and mounting the resistor so that its body does not touch conductors or other insulators setting up undesired or inadvertant leakage paths.

2. Unknown Resistance External to the Bridge.

The Model 5152 Remote Test Chamber shown in Fig. 2 is used for testing insulation or making other external shielded measurements. This test chamber is equipped with an integral 60-inch teflon-insulated triaxial cable fitted with a connector for attaching to the mating connector in the Shielded Measuring Compartment in the bridge. The chamber and connecting cable are rated for continous operation at temperatures as high as 200°C.

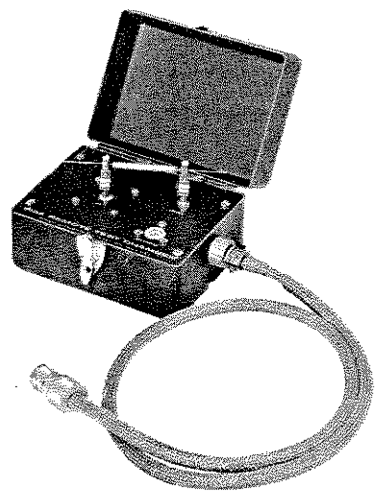


Fig. 2 Model 5152 Remote Test Chamber

The electrical connections are made through banana jacks in the chamber. The Grayhill #2-1 Test Clips as shown in Fig. 2 are furnished to facilitate installing unknowns with axial leads. The banana jacks of course, can be used with any other connectors or resistor holders.

To use the Model 5152 Remote Test Chamber, fasten its cable connector into the mating connector located in the Measuring Compartment in the Bridge, and connect the unknown resistor between the HI and GROUND banana jacks in the Test Chamber (using the Grayhill test clips if possible).

The third banana jack in the Remote Test Chamber is GUARD; it is connected through the inner shield braid of the triaxial cable to the guard connection in the Bridge.

Guarding is used extensively in the Bridge to reduce the errors caused by spurious leakage currents. Guarding should also be employed in the construction of test electrodes fitted to the Remote Test Chamber, in order to obtain the greatest accuracy from the bridge measurement.

The guard conductors are driven from the galvanometer junction of the low impedance standard arms of the bridge; a total resistance less than 10^{11} ohms from guard to ground will shunt the standards sufficiently to create errors great enough to impair the rated accuracy of the bridge. Great care has been taken in the construction of the bridge to keep the GUARD to GROUND resistance substantially higher than 10^{11} ohms, and care should be taken by the user to maintain that high level.

Fig. 3 is a simplified schematic diagram showing the electrical connections of the standard and readout resistors, the unknown, the null detector, and the guarding. A more extensive discussion of the circuit operation and guarding will be found in Section IV Circuit Description.

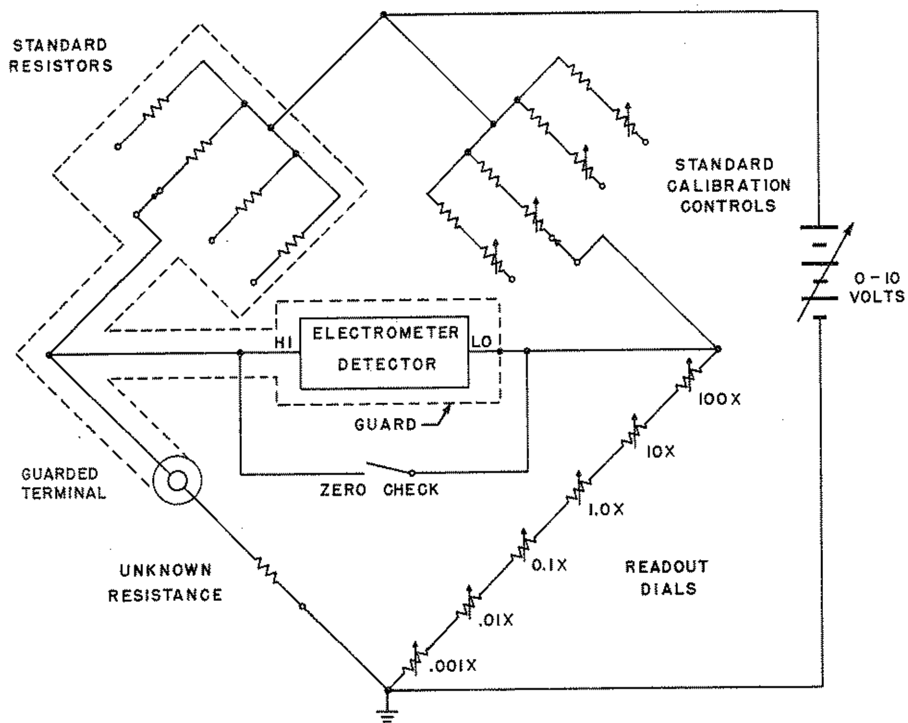


Fig. 3 Model 515 Megohm Bridge, Simplified Schematic Diagram

In cases where measurements with the unknown external to the bridge are necessary and the Model 5152 Remote Test Chamber is not suitable, the user can make his own holding fixture and connect it to the bridge.

Teflon insulated triaxial cable should be used for the connection. The central conductor is the High Impedance conductor; the inner shield braid is the Guard, and is driven from the low impedance arms of the bridge; and the outer braid is GND, to provide shielding. Amphenol 21-529 is a suitable cable.

The connector should also be teflon insulated. Gremar 7991 is satisfactory. Fig. 4 shows the connector and cable.

F. EXTERNAL BRIDGE VOLTAGE SUPPLY

Bridge voltages higher than the 10 volts available from the internal supply are desired when measuring resistances greater than about 10^{14} ohms, or in studying the voltage coefficient of a resistor.

A UHF connector labelled EXTERNAL INPUT is mounted on the rear of the bridge cabinet for ready connection of a high voltage source. The shell of the connector is at ground potential, and this grounds one terminal of the external bridge supply. The central conductor is the high - voltage lead. The bridge is insulated so that the external bridge voltage can be as high as 1000 volts.

Either the Keithley Model 241 or the 240 Regulated High Voltage Supply makes a very satisfactory source for external bridge voltage. The over-current protection on each is an important feature in preventing damage to the bridge resistors or to the unknown.

When using external bridge supply, set BRIDGE VOLTS to EXT after connecting the supply to the UHF receptacle on the rear panel. Do not apply more than 100 volts unless the x 100 or the x 10 dial is in a position other than "0", for too much current will flow through the bridge resistors. With the recommended Model 240 or 241 Regulated Voltage Supply the over current protection will prevent damage in the event this precaution is not observed.

In making voltage coefficient measurements, it should be kept in mind that the voltage applied to a Wheatstone Bridge is greater than the voltage appearing across the unknown resistance being measured. The relationship between the bridge voltage and the voltage across the unknown is given in Section G, below.

The shielded measuring compartment in the bridge has a safety switch which is operated when the door is closed. This switch operates a relay which applies the voltage from the external bridge supply to the bridge circuit. With the door open, the voltage is removed, so that the unknown can be changed without possible harm to the operator.

When the unknown is located outside the bridge, and the FUNCTION switch set to EXTERNAL OPERATE, this safety interlock is removed from the circuit. Unless the external bridge voltage supply is turned off or disconnected, voltages dangerous to the operator may be present at the unknown terminals. A convenient means of disconnecting the source is to switch the BRIDGE VOLTAGE from EXT to zero.

G. VOLTAGE ACROSS UNKNOWN AND STANDARD

In many cases, particularly in measuring coefficients of resistors. it is important to know the voltage across the unknown. In measuring the leakage resistance of capacitors, the applied voltage must be known to avoid breakdown. Also, for rated accuracy, the voltage across the standard resistor must not exceed ten volts.

If the bridge voltage is E, the unknown resistance X, and the standard resistance S, then the voltage across the unknown is:

$$E_X = E \frac{X}{X + S}$$

and the voltage across the standard is:

$$E_S = E \frac{S}{X + S}$$

The bridge voltage is read from the BRIDGE VOLTS dial or from the external bridge voltage supply. The standard resistance is the value indicated by the multiplier dial.

H. ACCURACY CONSIDERATIONS

The accuracy of measurement of an unknown resistor in a Wheatstone Bridge depends primarily on the accuracy and stability of the other three arms in the bridge, upon the resolution of the variable arm, and upon the ability of the null detector to respond to the small incremental changes in the variable arm. There are also numerous secondary effects. These will all be discussed below.

1. Null Detector Sensitivity.

To be able to detect a desired fractional deviation of the unknown, corresponding to the wanted percent accuracy of the measurement, the required null detector sensitivity is given by the approximate expression*:

$$e = E \frac{S\,x}{(S + X)^2}$$

e is the null detector signal in volts
x is the incremental part of the unknown resistance
E is the Bridge Potential in volts
S is the Standard Resistance, in ohms
X is the Unknown Resistance, in ohms

For resolutions of 0.1% in the unknown,

$$x = 0.001X$$

If X and S are approximately equal, and the Bridge Potential is 10 volts,

$$0.001X = 0.001S,$$

and $$e = \frac{10\ S\ (0.001S)}{(S + S)^2}$$

$$e = 0.0025 \text{ volts}$$
(2.5 millivolts)

*See Electrical Measurements by F. K. Harris. John Wiley & Sons, N. Y. 1952

In the case when X is approximately 10 S,

$$x = 0.001X = 0.01S$$

and $$e = \frac{10\ S\ (0.01S)}{(S + 10\ S)^2}$$

$$e = .0008 \text{ volts}$$
$$(0.8 \text{ millivolts})$$

The maximum sensitivity of the null detector in the Model 515 Megohm Bridge is one millivolt per meter dial division, and is thus sufficient for the rated accuracy of the bridge. Care should be taken, however, to be certain that the detector sensitivity and the bridge potential are great enough and the resistance of X and S are sufficiently close to each other to obtain the expected accuracy of measurement.

A check on the sensitivity of the system may be made by unbalancing the bridge readout dials a given percentage and observing the null detector deflection.

2. Null Detector Zero Drift.

Vacuum tube electrometers drift about one to two millivolts per hour, and this rate can be expected in the Null Detector. Obviously, a false balance is indicated if the meter points to zero, indicating balance, when in reality there are several millivolts at the input.

This error is easily eliminated by adjusting the null detector to zero while the PUSH TO READ button is released, then depressing the button and balancing the bridge.

3. Resolution of the Readout.

Using only the readout dials x10 through x.001, full rotation of the x.001 dial is 0.1% of the total setting. The dial can be easily read to one-twentieth of its full rotation, giving a readout resolution of 0.005%. This is ten times the best accuracy specified for any range.

When using all the dials, the readout resolution is very much greater than the maximum accuracy.

4. Accuracy of the Readout Resistors, the Standard Resistors, and the Standard Calibration Controls. (See Fig. 3 for the location of each of them in the Wheatstone Bridge Circuit).

The accuracy of the resistors on the switches controlled by each Readout Dial (RESISTANCE, OHMS) is:

x100	x10	x1	x.1	x.01	x.001
0.5%	0.02%	0.02%	0.02%	0.1%	1.0%

Maximum accuracy with the bridge is obtained when using the dials x10 through x.001. This is because the most accurate readout resistors are used, and also because the unknown resistance and the standard resistance are sufficiently close that the null detector has enough sensitivity with bridge voltages less than ten volts (see Section III H. 1).

The x100 dial has only 0.5% resistors associated with it because of the extremely high cost of more accurate high value resistors, and because resistors above 10^{13} ohms are not very stable high accuracy measurements are not warranted.

The resistors on the x.01 and x.001 dials are less accurate because they are not followed by enough dials to give high resolution, and their accuracies are great enough for rated accuracy when using the x1.0 to x.001 dials.

With the MULTIPLIER dial in either the 10^5 or 10^6 position all three arms in the bridge itself are wirewound resistors accurate to .02%, permitting the unknown to be measured to an accuracy of .05%.

With the MULTIPLIER in the 10^7 position, after the Standardization process, the bridge accuracy is that of the previous range (.05%) plus the error introduced by standardizing, which is conservatively set at .05%.

Following this pattern, the accuracy of the bridge at each successive step of the multiplier dial is the accuracy of the previous step plus the .05% standardizing error. It is in this fashion that the accuracies in the specifications up thru 10^{12} ohms were derived.

From 10^{13} to 10^{14} ohms, enough secondary effects are present to warrant the 0.5% rating, and above 10^{14} ohms, the x100 dial is used, adding enough further error to bring the overall accuracy rating to 1.0%.

The standard resistors used are as follows:

Multiplier	Resistor Type	Accuracy
10^5	Wire Wound	0.02%
10^6	" "	0.02%
10^7	Deposited Carbon	1.0 %
10^8	" "	1.0 %
10^9	Sealed Hi-Meg	2.0 %
10^{10}	" "	2.0 %
10^{11}	" "	2.0 %
10^{12}	" "	2.0 %

The Standard Calibration Controls arm is either a wirewound resistor accurate to 0.02%, or deposited carbon resistors in series with trimming potentiometers.

5. Temperature and Voltage Coefficient of Bridge Resistors.

The wirewound resistors employed are free from voltage coefficient. They use one of the lowest temperature coefficient of resistance alloys available, changing 20 parts per million per ^{O}C, or 0.002%/^{O}C. They are measured at room temperature, 25^{O}C, and for greatest accuracy, the bridge should be used near this temperature.

The deposited carbon and Hi-Meg resistors have substantially higher temperature coefficients of resistance than the wire-wound resistors. But if the bridge is allowed to come to its working temperature and standardized, it will have its rated accuracy unless the temperature changes. In this case it should be restandardized.

Deposited carbon and Hi-Meg resistors also exhibit voltage co-efficient of resistance. The Hi-Meg resistors used in the bridge are spiralled and have about one tenth the voltage coefficient of standard Hi-Meg units. Nevertheless, the voltage across these resistors should not exceed 10 volts for maximum accur-acy. See Section G. Voltage Across Unknown and Standard Re-sistors.

6. Leakage $R_e$sistance Across the Unknown.

10^{10} ohms shunting one megohm (10^{6} ohms) produces a change of 0.01%; and 10^{15} ohms shunting 10^{12} ohms produces a 0.1% change. With high resistance resistors and high accuracies leakage re-sistance is an important consideration.

The terminals of the Model 515 Megohm Bridge have been carefully made with teflon insulation, and guarding has been employed extensively. The major concern of the operator in using the bridge is to keep the insulation clean and dry. The user, how-ever, should be greatly concerned with the bobbin and housing or casing of his unknown resistor and with any specially built holding fixture. Paper base bakelite which has been handled and allowed to remain in a humid atmosphere has a surprisingly low resistance. Glass envelopes which have been handled and have finger oil and salt paths between fused-in wire conductors, or simple water vapor paths, also can have a surprisingly low resistance. Extreme care is necessary to avoid unsuspected errors or instabilities in measuring high resistances.

7. Errors Caused by Guard to Ground Resistance.

Guarding, as described in Fig. 3 Section III E, is used exten-sively in the construction of the Model 515 Megohm Bridge to reduce errors caused by undesired leakage currents. The Guard conductors are driven from the low impedance side of the Null Detector. Resistance from Guard to Ground shunts the resistors on the Readout Dial switches and the Standard Calibration controls. The Readout Dial resistors of x10 to x.001 may be as high as 10 megohms with 0.02% tolerance. If ten megohms is shunted with 5×10^{10} ohms, an additional 0.02% error results. In the building of the bridge, the limit of 10^{11} ohms (0.01% shunting error) was established for the lowest Guard to Ground resistance, and the user should do nothing to lower it.

The Guard conductors are mostly inside the instrument cabinet but Guard is exposed in the connector on the external unknown. Extreme care must be taken at all times, with the instrument cover on or off, to maintain the cleanliness and dryness of the Guard to Ground insulators.

The Guard conductor is also exposed in the 5152 Remote Test Chamber. If any resistor-holding electrode is connected to the Model 5152 Guard, it too, must have a resistance greater than 10^{11} ohms to ground, for maximum accuracy.

8. Time Constants - Slow Responses

Ten picofarads and 10^{12} ohms have a time constant of 10 seconds; the wiring capacitances in the bridge and null detector input combined with an unknown of about 10^{12} ohms produces a time constant of several seconds.

The time constant is apparent in the length of time required for the null detector meter to reach its final position after an adjustment has been made in the bridge.

For maximum measuring accuracy, the bridge null must be carefully determined, and readings taken only after the null detector meter pointer has stopped moving.

The bridge has been carefully designed to keep the stray capacitances as low as possible, so that measurements can be made as rapidly as possible. In measuring resistors greater than 10^{12} ohms, the standard resistor is never greater than 10^{12} ohms, thus the time constant is never longer than several seconds.

Measuring the leakage resistance of capacitors with the Model 515 Megohm Bridge can be a very tedious process, for with good capacitors with very little leakage, the time constants with the bridge impedances can be as long as several days. It is recommended that this sort of measurement be done by charging the capacitor to a known voltage and measuring its voltage at known times later with a Keithley electrometer voltmeter.

9. Transients Caused by Push-to-Read Switch

Whenever two conductors have been making contact and are separated, a charge appears on the conductors. In the Model 515 Megohm Bridge, this charge transfer is apparent in the null detector meter when the Push-to-Read switch is operated, removing the short circuit across the null detector input. It is most noticeable when using the 10^{12} ohm multiplier and measuring unknowns of 10^{12} ohm or greater.

The Push-to-Read switch has been very carefully designed and constructed to minimize charge transfer, but a few millivolts are often induced in the bridge circuit by its operation. This is not harmful, but it is necessary to wait each time the switch is operated, for several time constants during which the voltages come to their steady-state value, and the null-detector meter pointer stops drifting.

10. Verification of Accuracy

In checking the accuracy of prototype bridges, resistors of 10^5, 10^6, and 10^7 ohms were compared between the Model 515, and a Leeds and Northrup Guarded Wheatstone Bridge, Catalog 4232-B. These measurements were thus traceable to the National Bureau of Standards, and were verified with various resistor manufacturers. Agreement was within 0.01%, which is well within Model 515 specifications.

Resistance values between 10^7 and 10^{10} ohms were simulated by a delta-wye Transformation; AIEE Transactions Paper 58-556 gives the details.

Resistance values up to 10^{11} ohms were also measured carefully by measuring the discharge times of accurately known capacitors. Above 10^{11} ohms, stray capacitances introduced too much error. Both the delta-wye and capacitor discharge measurements were well within the specified accuracy of the Model 515. The 10^{12} ohm range was checked by measuring ten 10^{11} ohm resistors and then connecting them in series. Agreement was obtained within 0.1%. From 10^{12} to 10^{15} ohms, accuracy is assured by the careful measurement of the resistors in the x100 and x10 switches in the Readout arm of the bridge.

Ten resistors connected in parallel, measured accurately, and then connected in series is another method of obtaining high value resistors to great accuracies, and was used extensively in developing the bridge in production tests. This method is described in "Electrical Measurements" by Harris. See Section H, part 1.

In the manufacture of each Model 515 Megohm Bridge, each of the bridge resistors is measured and found to be within its rated limits before the bridge is assembled. After assembly, each step on each decade is checked with a precision decade box as the unknown resistor. Following this, Keithley developed standard resistors are used to check each step of the multiplier switch. The internal applied bridge voltage supply and null detector sensitivity and zero drift are also checked.

CIRCUIT DESCRIPTION - SECTION IV

The circuit of the Model 515 Megohm Bridge consists of three major components: the power supply, the electrometer null-detector and the Wheatstone Bridge.

A. POWER SUPPLY

The power supply consists of a transformer, rectifiers and filters, a transistor regulator supplying 12 volts dc, and a transistor converter which supplies voltages isolated from ground to the null-detector. A portion of the 12 volts dc is used to polarize the bridge.

A detailed description of the power supply is as follows: Drawing 14522-D at the rear of the manual is the complete schematic. T1 is the power transformer operating from the power line. The primary may be connected for either 110 or 220 volts. One secondary is center-tapped and, with diodes D9 and D10, supplies 18 volts at 250 ma. The other secondary and half-wave rectifier D11 supplies 20 volts at 10 ma. The 18 volts is applied to the collector of Q1 and is dropped to 12 volts through the action of Q1 and the associated regulator circuitry.

Q4 and Q5 form a difference amplifier which compares a portion of the 12 volt output with the reference voltage derived from zener diode D14. Q3 and Q2 are used as amplifier and driver for output transistor Q1. D13 is supplied from the 20 volt supply referred to above. This supply is "boot-strapped" on the 12 volt regulated supply to furnish a regulated return point for R212, the load resistor for Q3. The circuitry is so designed that any change in load current, or line voltage is compensated perfectly within the operating range. The regulated 12 volts supplies the transistor inverter, consisting of transistors Q6 and Q7 and transformer T2, and also the ten volt bridge polarizing potential.

Transformer T2 and transistors Q6 and Q7 form a dc inverter operating at approximately 200 cps. The feedback winding to the bases of the transistors provides the oscillator drive. The primary inductance of the transformer determines the frequency of oscillation. T2 is especially well insulated to provide the necessary insulation of guard to ground in the bridge circuit. Since the 12 volt source is exceedingly well regulated, all the secondary voltages are unaffected by line voltage variation. Therefore, the operation of the null-detector is not affected by line voltage variations.

B. NULL DETECTOR:

Fig. 4 is a simplified circuit diagram of the null detector. The component designations are the same as used in the complete schematic. The power supply potentials are represented by batteries for simplicity.

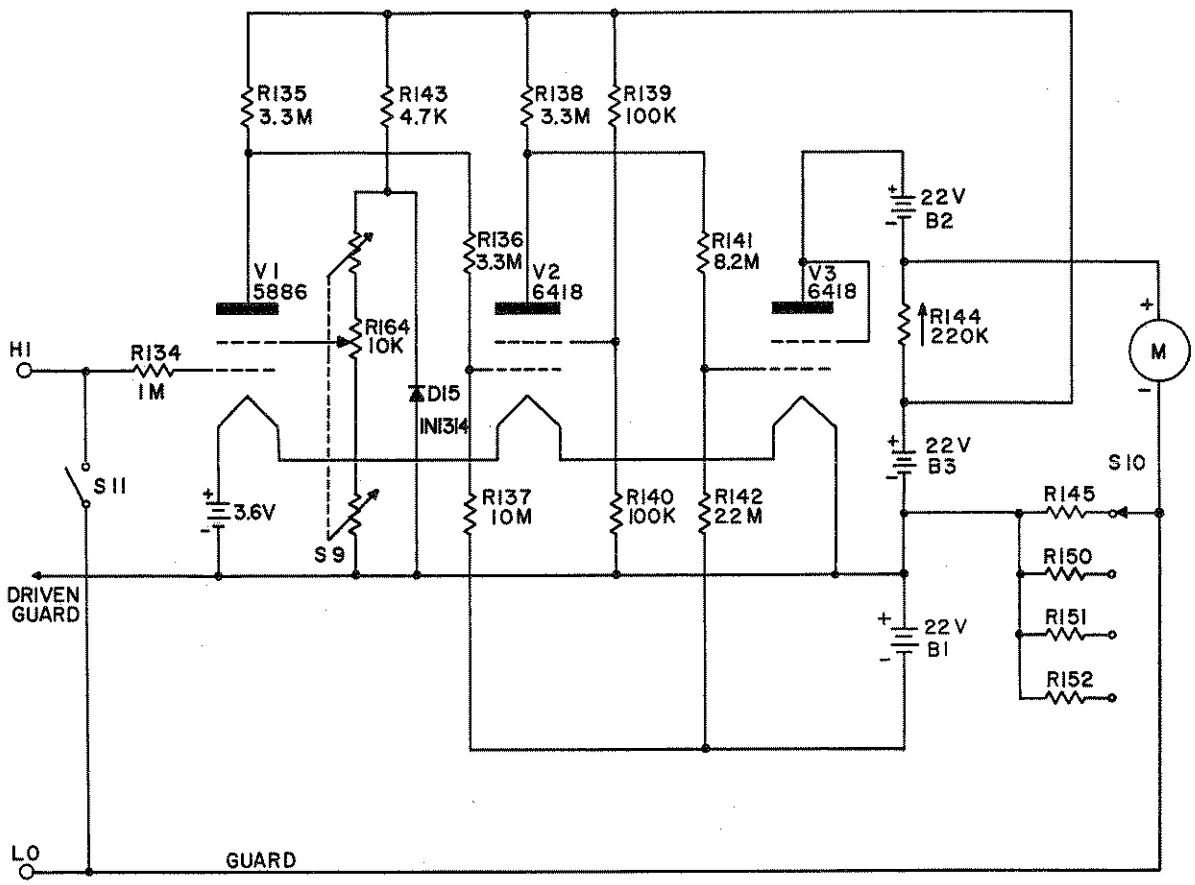


FIG. 4

The filaments of V1, V2 and V3 are in series and supplied with 3.6 volts. This voltage also is used to bias the electrometer tube, V1. V2 is an amplifier and V3 is the output tube. The output circuit is somewhat unique and operates as follows: The meter will have zero deflection only if there is no potential difference between the plus terminal of B3 and minus terminal of B2. This will occur only if the drop across R144 is equal to the potential of B3. This zero output condition is set by adjusting the screen voltage of V1 with the fine zero control, R164, and the coarse zero control, S9. An input signal will cause the plate current of V3 to change, and the drop across R144 will increase or decrease, depending on the polarity of the signal. A current will then flow thru the meter and one of the range resistors on S10, the sensitivity switch. Since the low impedance side of the input is the minus meter terminal the potential drop across the range resistor will alter the potential of the filament circuit in such a way that the grid-filament potential of V1 will remain nearly constant. The filament is the "Driven Guard" since its instantaneous ac potential is nearly equal to the ac potential of the input signal. All the guarded points of the bridge except S11 are returned to this point. This acts as a driven shield and a considerable increase in response speed is realized in certain cases.

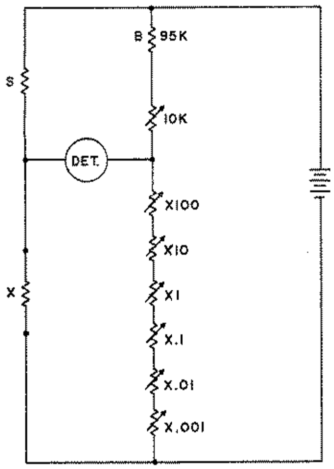


FIG. 5
SIMPLIFIED SCHEMATIC OF BRIDGE IN OPERATE POSITION

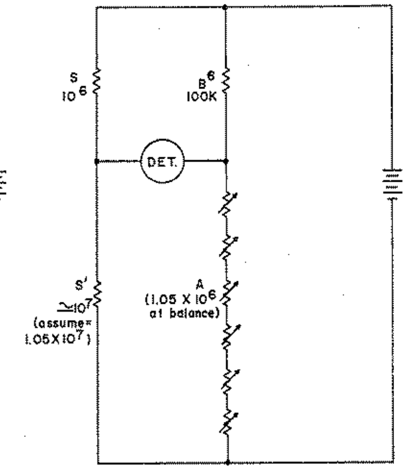


FIG. 6
BRIDGE IN STANDARDIZE POSITION, MULTIPLIER AT 10⁶

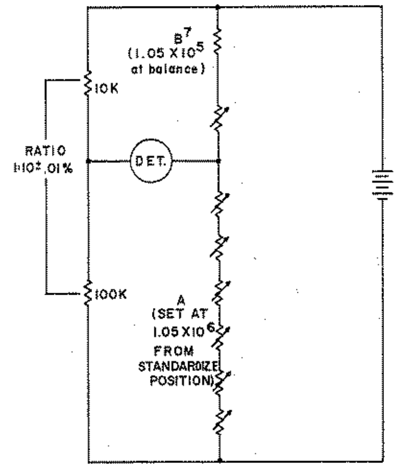


FIG. 7
BRIDGE IN CALIBRATE POSITION, MULTIPLIER AT 10⁶

C. WHEATSTONE BRIDGE

The simplified bridge circuit is shown in Fig. 5. One ratio arm, A, is the six read-out dials. The other ratio arm, B, is nominally 100 K ohms for each multiplier range. With the multiplier set at 10^5 the standard resistor S and the ratio arm B are both 10^5 ohm .02% wirewound units. When the multiplier is set at 10^6, S is a 10^6 ohm .02% wire wound and B is 10^5 ohm .02%. With the multiplier at 10^7 or higher the standard resistor is a carbon film unit of limited accuracy and B is a 95 K fixed resistor in series with a 10 K rheostat. By the standardizing procedure described below B is set to an appropriate value to compensate for error in S and the bridge will be direct reading.

The first step in standardizing is done with the multiplier at 10^6 and the FUNCTION switch at STANDARDIZE. The basic circuit is then as shown in Fig. 6. The unknown X has been disconnected and the standard resistor for the 10^7 range is in its place. Balancing the bridge with the read-out dials will give the value of the 10^7 standard as compared to the 10^6 standard. Since the 10^6 standard is an accurate wirewound unit the value indicated for the 10^7 resistor is quite accurate. In Fig. 3 the 10^7 ohm resistor is assumed to be 5% high and the read-out dials will indicate 10.500.

Leaving the read-out dials set the FUNCTION switch is next set to CALIBRATE. As shown in the simplified schematic of Fig. 7 the standard and unknown resistors are replaced with a network of 10:1 ratio, accurate to .01%. Ratio arm B is now B^7, the adjustable leg associated with the 10^7 ohm standard. Rebalancing the bridge with B^7 a null will be obtained when B^7 is 1.05×10^5 ohms.

This completes the standarization of the 10^7 ohm standard resistor. After this, when using this resistor as a standard its 5% error is exactly corrected for by B7 being 5% high.

To standardize the 10^8 ohm standard the multiplier is set at 10^7, the FUNCTION switch is returned to STANDARDIZE, and the bridge is again balanced with the read-out dials. The indicated read-out is the value of the 10^8 ohm resistor compared to the corrected 10^7 ohm standard. Next the FUNCTION switch is set to CALIBRATE and the bridge is rebalanced with ratio arm B^8.

After following this procedure in sequence for multiplier positions 10^6 thru 10^{11} the bridge is completely standardized and will be direct reading on all ranges.

D. OVERVOLTAGE PROTECTION

The function of V4, a gas regulator tube, is to prevent damage to the readout resistors from excessive bridge voltage. It is connected thru auxiliary contacts on the x100 and x10 dials across the bridge voltage. Thus if both dials are at zero the circuit is complete and, if more than 133 volts is applied to the bridge, the tube will conduct current. With a Keithley Model 240 or 241 Voltage Supply this current will be enough to trip the overload relay and no damage will be done. If an unprotected source is used it is possible that V4 would be ruined and then possibly the readout resistors would overheat from excessive current.

Very few maintenance problems will arise from ordinary use of the bridge. The components used have adequate safety margins and, since the total power consumption is only 10 watts, very little temperature rise will occur even with continuous operation.

If it becomes apparent that the bridge is not working properly the first step is to check the voltage on the printed circuit boards. Remove the six screws on each side and the two on top and remove the cover. Check the voltages on the main power supply board and null detector board as shown on Drawing 14363-C.

If the difficulty is determined to be in the null detector proper the following procedure will be helpful in isolating the cause:

Short circuit the feedback by jumpering the feedback resistor in use. These resistors are mounted on S-10, MILLIVOLTS PER DIVISION. The sensitivity will now be about 500 microvolts per division and it will be rather difficult to keep the meter on-scale with the ZERO control. However, if it is possible to swing the tube voltages thru the values indicated on 14363-C the stage is working satisfactorily. Start with V1 and work thru to V3. Once the defective stage is located check the tube itself and then the associated components. If it is necessary to replace the electrometer tube avoid touching the glass near the lead wires.

Once the bridge is operating a good check on the accuracy may be made by placing the multiplier at 10^5 and the FUNCTION switch at STANDARDIZE. A null balance should be obtained with the readout dials at 10.000 $\pm$.05%. If the reading is not within these limits it is recommended that the unit be returned to the factory for repairs.

The overvoltage tube, V4, will ordinarily not carry any current and should last indefinitely. However, if the instrument has been used with a supply lacking adequate overload protection it is possible the tube may be damaged. If this has happened it is likely that other components have been damaged also. Check the resistors in arm A and B of the bridge (R111 thru R123 and R171 thru R181).

230 volt operation:

To change the power line voltage to 230 volt remove the two jumpers at the bottom of the main power supply board and connect a single jumper as shown in the circuit schematic, 14522-D. Be sure the line cord is removed from the power when doing this. Replace the $\frac{1}{4}$ ampere 3AG fuse with a 1/8 ampere unit.

SECTION 6. REPLACEABLE PARTS

6-1. REPLACEABLE PARTS LIST. The Replaceable Parts List describes the components of the Model 515. The List gives the circuit designation, the part description, a suggested manufacturer, the manufacturer's part number and the Keithley Part Number. The name and address of the manufacturers listed in the "Mfg. Code" column are in Table 2.

6-2. HOW TO ORDER PARTS.

a. For parts orders, include the instrument's model and serial number, the Keithley Part Number, the circuit designation and a description of the part. All structual parts and those parts coded for Keithley manufacture (80164) must be ordered through Keithley Instruments, Inc. or its representative. In ordering a part not listed in the Replaceable Parts List, completely describe the part, its function and its location.

b. Order parts through your nearest Keithley representative or the Sales Service Department, Keithley Instruments, Inc.

amp	ampere	M	mega (10^6)
		m	milli (10^{-3})
CerD	Ceramic, Disc	Mfg.	Manufacturer
Comp	Composition		
		Ω	ohm
DCb	Deposited Carbon		
		PMC	Paper, Metal Cased
EMC	Electrolytic, Metal Case	Poly	Polystyrene
ETB	Electrolytic, tubular		
		μ	micro (10^{-6})
f	farad		
		v	volt
GCb	Glass enclosed carbon		
		w	watt
k	kilo (10^3)	WW	Wirewound
		WWVar	Wirewound Variable
Loc.	Location		

TABLE 1. Abbreviations and Symbols.

MODEL 515 REPLACEABLE PARTS LIST
(Refer to Schematic Diagram 14522D for circuit designations)

CAPACITORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Loc.
C101	22 pf	1000 v	CerD	56289	5GAQ22	C72-22P	
C102	22 pf	600 v	CerD	72982	ED22	C22-22P	
C103	22 pf	600 v	CerD	72982	ED22	C22-22P	
C104	.047 μf	1000 v	Poly	96733	MW94 M10473	C67-.047M	
C201	100 μf	50 v	EMC	56289	TVL2326	C33-100/100M	
C202	100 μf	25 v	ETB	56289	TVA1207	C10-100M	
C203	100 μf	50 v	EMC	56289	TVL2326	C33-100/100M	
C204	100 μf	25 v	EMC	37942	FP335A	C100-100M	
C205	1000 μf	15 v	EMC	14655	BO 040	C59-1000/1000M	
C206	10 μf	25 v	ETB	14655	BBR10-25	C10-10M	
C207	500 μf	25 v	EMC	14655	AA0120	C58-500M	
C208	.05 μf	200 v	PMC	00656	P82	C18-.05M	
C209	500 μf	50 v	EMC	14655	AA0160	C57-500M	
C210	50 μf	25 v	ETB	56289	TVA1206	C10-50M	

DIODES

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.	Loc.
D1	Silicon	1N3253	02735	RF-20	
D2	Silicon	1N3253	02735	RF-20	
D3	Silicon	1N3253	02735	RF-20	
D4	Silicon	1N3253	02735	RF-20	
D5	Silicon	1N3253	02735	RF-20	
D6	Silicon	1N3253	02735	RF-20	
D7	Silicon	1N3253	02735	RF-20	
D8	Silicon	1N3253	02735	RF-20	
D9	Silicon	1N3253	02735	RF-20	
D10	Silicon	1N3253	02735	RF-20	
D11	Silicon	1N3253	02735	RF-20	
D12	Silicon	1N3253	02735	RF-20	
D13	Zener	1N1314	99942	DZ-2	
D14	Zener	1N706	12954	DZ-1	
D15	Zener	1N1314	99942	DZ-2	

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Loc.
DS1	Miniature Lamp, 6.3 v at 0.2 amp (Mfg. No. 51)	08804	PL-8	
DS2	Miniature Lamp, 6.3 v at 0.2 amp (Mfg. No. 51)	08804	PL-8	
F1 (117v)	Fuse, .25 amp (Mfg. No. 313, 250)	75915	FU-17	
F1 (234v)	Fuse, .125 amp (Mfg. Type HDL)	75915	FU-20	
J1	Guarded Input Terminal (Mfg. No. 6804)	91737	CS-64	
J2	Triaxial External Operate Connector (Mfg. No. 5632A)	91737	CS-67	
J3	UHF Receptacle, External Volts (Mfg. No. 6804)	91737	CS-64	
J4	3-Terminal Accessory Outlet (Mfg. No. 160-2)	02660	CS-66	
K1	Relay, DPDT	80164	RL-12	
M1	Meter	80164	ME-34	
P1	3-Wire Power Cord, 6 feet (Mfg. No. 4638-13)	82879	CO-2	
S1	Rotary Switch, FUNCTION, 4-position	80164	SW-87	
S2	Rotary Switch, RANGE, 8-position	80164	SW-80	
S3	Rotary Switch, BRIDGE VOLTS, 120-position	80164	SW-91	
S4	Rotary Switch, DECADE X100	80164	SW-123	
S5	Rotary Switch, DECADE X10	80164	SW-123	
S6	Rotary Switch, DECADE X1	80164	SW-122	
S7	Rotary Switch, DECADE X0.1	80164	SW-122	
S8	Rotary Switch, DECADE X.01	80164	SW-122	
S9	Rotary Switch, COARSE ZERO, 11-position	80164	SW-88	
S10	Rotary Switch, SENSITIVITY, 4-position	80164	SW-92	
S11	Zero Switch Special Push Button	80164	14377A	
S12	Toggle Switch, on-off S.P.S.T.	80164	SW-4	
S13	Door safety switch	80164	SW-94	

MISCELLANEOUS PARTS (Cont'd)

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Loc.
T1	Power Supply Transformer	80164	TR-39	
T2	Inverter Transformer	80164	TR-40	

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Loc.
R101	10 kΩ	.02%, 1/2 w	WW	80164		(1)	
R102	100 kΩ	.02%, 1/2 w	WW	80164		(1)	
R103	100 kΩ	.02%, 1/2 w	WW	15909	1252	R47-100K	
R104	1 MΩ	.02%, 1/2 w	WW	15909	1252	R47-1M	
R105	10 MΩ	1%, 1/2 w	DCb	00327	N11A	R12-10M	
R106	100 MΩ	1%, 2 w	DCb	91637	DC-2	R14-100M	
R107	10^9 Ω	+3-0%, 1/R w	GCb	63060	RX-1S	R20A-10^9	
R108	10^{10} Ω	+3-0%, 1/R w	GCb	63060	RX-1S	R20A-10^{10}	
R109	10^{11} Ω	+3-0%, 1/R w	GCb	63060	RX-1S	R20A-10^{11}	
R110	10^{12} Ω	+3-0%, 1/R w	GCb	63060	RX-1S	R20A-10^{12}	
R111	100 kΩ	.02%, 1/2 w	WW	15909	1252	R47-100K	
R112	94.5 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-94.5K	
R113	94.5 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-94.5K	
R114	94.5 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-94.5K	
R115	94.5 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-94.5K	
R116	94.5 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-94.5K	
R117	94.5 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-94.5K	
R118	10 kΩ	10%, 2 w	WW	12697	43-10K	RP27-10K	
R119	10 kΩ	10%, 2 w	WW	12697	43-10K	RP27-10K	
R120	10 kΩ	10%, 2 w	WW	12697	43-10K	RP27-10K	
R121	10 kΩ	10%, 2 w	WW	12697	43-10K	RP27-10K	
R122	10 kΩ	10%, 2 w	WW	12697	43-10K	RP27-10K	
R123	10 kΩ	10%, 2 w	WW	12697	43-10K	RP27-10K	
R124	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R125	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R126	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R127	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R128	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R129	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R130	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R131	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R132	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R133	100 Ω	1%, 1/2 w	DCb	00327	N11A	R12-100	
R134	1 MΩ	10%, 1/2 w	Comp	01121	EB	R1-1M	
R135	3.3 MΩ	1%, 1/2 w	DCb	00327	N11A	R12-3.3M	

(1) R101 and R102 are a matched set, Keithley Part Number DR13992A.

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Loc.
R136	3.3 MΩ	1%, 1/2 w	DCb	00327	N11A	R12-3.3M	
R137	10 MΩ	1%, 1/2 w	DCb	00327	N11A	R12-10M	
R138	3.3 MΩ	10%, 1/2 w	Comp	01121	EB	R1-3.3M	
R139	100 kΩ	10%, 1/2 w	Comp	01121	EB	R1-100K	
R140	100 kΩ	10%, 1/2 w	Comp	01121	EB	R1-100K	
R141	8.2 MΩ	10%, 1/2 w	Comp	01121	EB	R1-8.2M	
R142	22 MΩ	10%, 1/2 w	Comp	01121	EB	R1-22M	
R143	4.7 kΩ	10%, 1/2 w	Comp	01121	EB	R1-4.7K	
R144	220 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-220K	
R145	10 kΩ	10%, 1/2 w	Comp	01121	EB	R1-10K	
R146	5 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-5K	
R147	Not Used						
R148	Not Used						
R149	420 Ω	1%, 1/2 w	DCb	00327	N11A	R12-420	
R150	4.3 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-4.3K	
R151	40 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-40K	
R152	390 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-390K	
R153	1.4 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-1.4	
R154	2 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-2K	
R155	1 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-1K	
R156	4 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-4K	
R157	4 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-4K	
R158	2 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-2K	
R159	1 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-1K	
R160	4 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-4K	
R161	4 kΩ	1%, 1/2 w	DCb	00327	N11A	R12-4K	
R162	Not Used						
R163	10 kΩ	10%, 1/2 w	Comp	01121	EB	R1-10K	
R164	10 kΩ	3%, 5 w	WWVar	73138	A	RP4-10K	
R165	1 kΩ	3%-1%, 3 w	WW	12697	CM27520NP	RP25-1K	
R166	Not Used						
R167	Not Used						
R168	Not Used						
R169	Not Used						
R170	10 kΩ	0.1%, 1/2 w	WW	15909	1252	R70-10K	
R171	2 kΩ	0.1%, 1/2 w	WW	15909	1252	R70-2K	
R172	4 kΩ	0.1%, 1/2 w	WW	15909	1252	R70-4K	
R173	4 kΩ	0.1%, 1/2 w	WW	15909	1252	R70-4K	
R174	10 kΩ	.02%, 1/2 w	WW	15909	1252	R47-10K	
R175	20 kΩ	.02%, 1/2 w	WW	15909	1252	R47-20K	

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Loc.
R176	40 kΩ	.02%, 1/2 w	WW	15909	1252	R47-40K	
R177	40 kΩ	.02%, 1/2 w	WW	15909	1252	R47-40K	
R178	100 kΩ	.02%, 1/2 w	WW	15909	1252	R47-100K	
R179	200 kΩ	.02%, 1/2 w	WW	15909	1252	R47-200K	
R180	400 kΩ	.02%, 1/2 w	WW	15909	1252	R47-400K	
R181	400 kΩ	.02%, 1/2 w	WW	15909	1252	R47-400K	
R182	1 MΩ	.02%, 1/2 w	WW	15909	1252	R47-1M	
R183	2 MΩ	.02%, 1/2 w	WW	15909	1252	R47-2M	
R184	4 MΩ	.02%, 1/2 w	WW	15909	1252	R47-4M	
R185	4 MΩ	.02%, 1/2 w	WW	15909	1252	R47-4M	
R186	10 MΩ	1/2%, 2 w	DCb	03888	PT-200	R52-10M	
R187	20 MΩ	1/2%, 2 w	DCb	03888	PT-200	R52-20M	
R188	40 MΩ	1/2%, 2 w	DCb	03888	PT-200	R52-40M	
R189	40 MΩ	1/2%, 2 w	DCb	03888	PT-200	R52-40M	
R201	68 Ω	10%, 1/2 w	Comp	01121	EB	R1-68	
R202	200 Ω	1%, 1/2 w	DCb	00327	N11A	R12-200	
R203	500 Ω	1%, 1/2 w	DCb	00327	N11A	R12-500	
R204	500 Ω	1%, 1/2 w	DCb	00327	N11A	R12-500	
R205	200 Ω	10%, 2 w	WW	71450	R252-200	RP22-200	
R206	1.5 kΩ	10%, 1/2 w	Comp	01121	EB	R1-1.5K	
R207	8.2 kΩ	10%, 1/2 w	Comp	01121	EB	R1-8.2K	
R208	1 kΩ	10%, 1/2 w	Comp	01121	EB	R1-1K	
R209	680 Ω	10%, 1/2 w	Comp	01121	EB	R1-680	
R210	820 Ω	10%, 1/2 w	Comp	01121	EB	R1-820	
R211	390 Ω	10%, 1/2 w	Comp	01121	EB	R1-390	
R212	27 kΩ	10%, 1/2 w	Comp	01121	EB	R1-27K	
R213	10 kΩ	10%, 1/2 w	Comp	01121	EB	R1-10K	
R214	3.3 MΩ	10%, 1/2 w	Comp	01121	EB	R1-3.3M	
R215	10 Ω	10%, 1/2 w	Comp	01121	EB	R1-10	
R216	10 Ω	10%, 1/2 w	Comp	01121	EB	R1-10	
R217	100 Ω	10%, 1/2 w	Comp	01121	EB	R1-100	
R218	10 Ω	10%, 1/2 w	Comp	01121	EB	R1-10	
R219	22 kΩ	10%, 1/2 w	Comp	01121	EB	R1-22K	
R220	470 Ω	10%, 1/2 w	Comp	01121	EB	R1-470	
R221	*	1%, 1/2 w	DCb	00327	N11A	R12-*	

* Nominal value, factory set.

TRANSISTORS

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Loc.
Q1	2N1535	04713	TG-7	
Q2	2N1381	01295	TG-8	
Q3	2N1381	01295	TG-8	
Q4	2N1381	01295	TG-8	
Q5	2N1381	01295	TG-8	
Q6	2N1375	01295	TG-15	
Q7	2N1375	01295	TG-15	

VACUUM TUBES

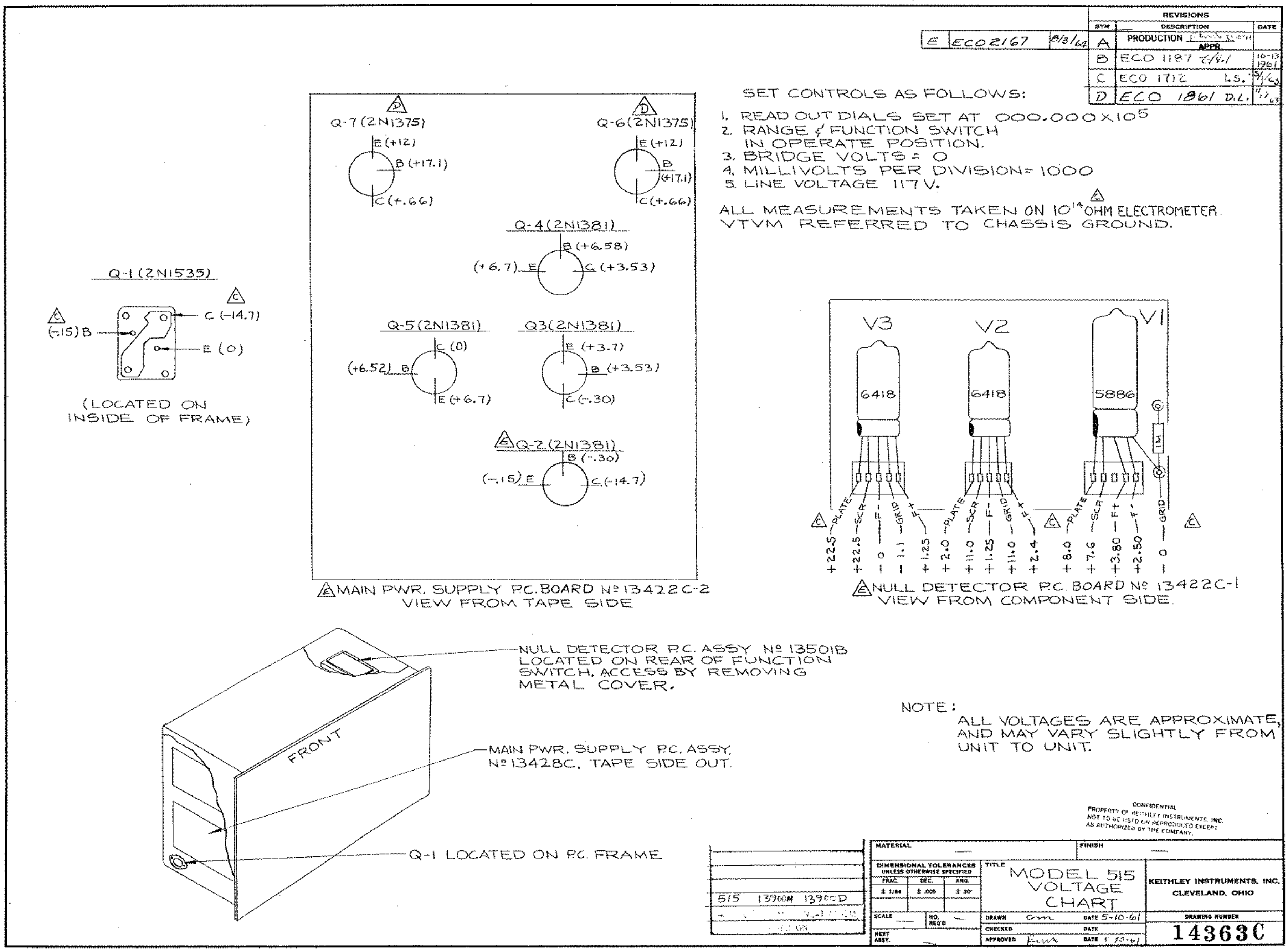
Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Loc.
V1	5886	94145	EV-5886-5X	
V2	6418	81453	EV-6418	
V3	6418	81453	EV-6418	
V4	OB2	86684	EV-OB2	

00327	Welwyn International, Inc. Cleveland, Ohio
00656	Aerovox Corp. New Bedford, Mass.
01121	Allen-Bradley Corp. Milwaukee, Wis.
01295	Texas Instruments, Inc. Semiconductor-Components Division Dallas, Tex.
02660	Amphenol-Borg Electronics Corp. Broadview, Chicago, Illinois
02735	Radio Corp. of America Commercial Receiving Tube and Semiconductor Division Somerville, N. J.
03888	Pyrofilm Resistor Co., Inc. Cedar Knolls, N. J.
04713	Motorola, Inc. Semiconductor Products Division Phoenix, Arizona
08804	Lamp Metals and Components Department G. E. Co. Cleveland, Ohio
12697	Clarostat Mfg. Co., Inc. Dover, N. H.
12954	Dickson Electronics Corp. Scottsdale, Ariz.
14655	Cornell-Dubilier Electric Corp. Neward, N. J.
15909	Daven Division Thomas A. Edison Industries McGraw Edison Co., Livingston, N. J.
37942	Mallory, P. R., and Co., Inc. Indianapolis, Ind.
56289	Sprague Electric Co. North Adams, Mass.
63060	Victoreen Instrument Co. Cleveland, Ohio

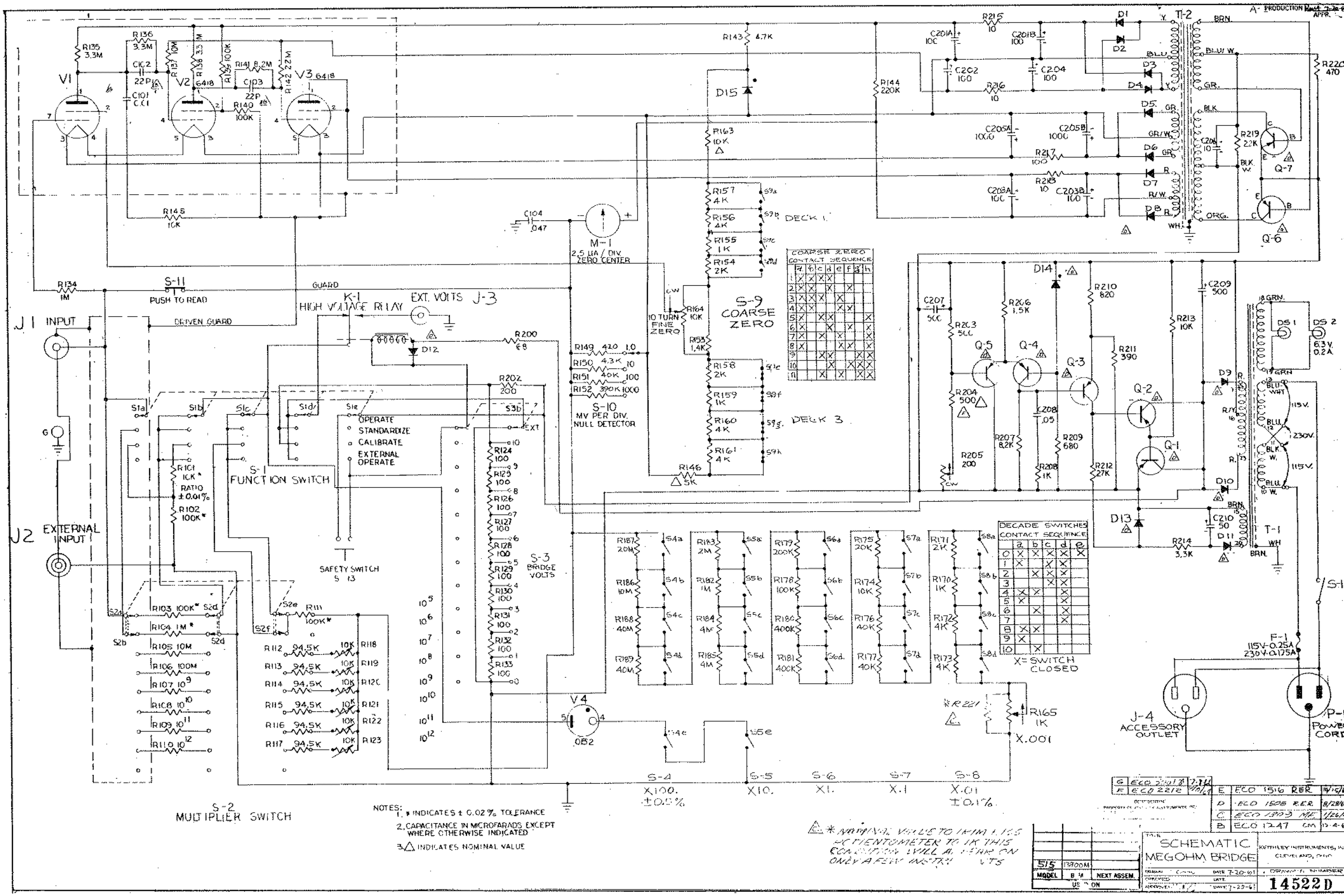
TABLE 2 (Sheet 1). Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)

71450	CTS Corp. Elkhart, Ind.	86684	Radio Corp. of America Electronic Components and Devices Harrison, N. J.
72982	Erie Technological Products, Inc. Erie, Pa.	91637	Dale Electronics, Inc. Columbus, Nebr.
73138	Helipot Division of Beckman Instruments, Inc. Fullerton, Calif.	91737	Gremar Mfg. Co., Inc. Wakefield, Mass.
75915	Littelfuse, Inc. Des Plaines, Ill.	94145	Raytheon Co. Semiconductor Division California Street Plant Newton, Mass.
80164	Keithley Instruments, Inc. Cleveland, Ohio	96733	San Fernando Electric Mfg. Co. San Fernando, Calif.
81453	Raytheon Co. Industrial Components Div. Industrial Tube Operation Newton, Mass.	99942	Hoffman Electronics Corp. Semiconductor Division El Monte, Calif.
82879	Royal Electric Corp. Pawtucket, R. I.		

TABLE 2 (Sheet 2). Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)



REVISIONS
SYM | DESCRIPTION | APPR. | DATE
A PRODUCTION
B ECO 1187 10-13 1961
C ECO 1712 L.S.
D ECO 1861 D.L.
E ECO 2167 8/3/64
SET CONTROLS AS FOLLOWS:
1. READ OUT DIALS SET AT 000.000X10^5
2. RANGE & FUNCTION SWITCH IN OPERATE POSITION.
3. BRIDGE VOLTS = 0
4. MILLIVOLTS PER DIVISION = 1000
5. LINE VOLTAGE 117 V.
ALL MEASUREMENTS TAKEN ON 10^14 OHM ELECTROMETER VTVM REFERRED TO CHASSIS GROUND.
Q-1 (2N1535)
(-.15) B
C (-14.7)
E (0)
(LOCATED ON INSIDE OF FRAME)
Q-7 (2N1375)
E (+12)
B (+17.1)
C (+.66)
Q-6 (2N1375)
E (+12)
B (+17.1)
C (+.66)
Q-4 (2N1381)
B (+6.58)
(+6.7) E
C (+3.53)
Q-5 (2N1381)
C (0)
(+6.52) B
E (+6.7)
Q3 (2N1381)
E (+3.7)
B (+3.53)
C (-.30)
Q-2 (2N1381)
B (-.30)
(-.15) E
C (-14.7)
MAIN PWR. SUPPLY P.C. BOARD Nº 13422C-2 VIEW FROM TAPE SIDE
V3
V2
V1
6418
6418
5886
1M
PLATE
SCR
F
GRID
F+
+22.5
+22.5
0
1.1
+1.25
+2.0
+11.0
+1.25
+11.0
+2.4
+8.0
+7.6
+3.80
+2.50
0
NULL DETECTOR P.C. BOARD Nº 13422C-1 VIEW FROM COMPONENT SIDE.
NULL DETECTOR P.C. ASSY Nº 13501B LOCATED ON REAR OF FUNCTION SWITCH, ACCESS BY REMOVING METAL COVER.
FRONT
MAIN PWR. SUPPLY P.C. ASSY. Nº 13428C. TAPE SIDE OUT.
Q-1 LOCATED ON P.C. FRAME
NOTE: ALL VOLTAGES ARE APPROXIMATE, AND MAY VARY SLIGHTLY FROM UNIT TO UNIT.
CONFIDENTIAL PROPERTY OF KEITHLEY INSTRUMENTS, INC. NOT TO BE USED OR REPRODUCED EXCEPT AS AUTHORIZED BY THE COMPANY.
515 13900M 13900D
MATERIAL
FINISH
DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED
FRAC. ± 1/64
DEC. ± .005
ANG. ± 30'
TITLE MODEL 515 VOLTAGE CHART
KEITHLEY INSTRUMENTS, INC. CLEVELAND, OHIO
SCALE
NO. REQ'D
NEXT ASSY.
DRAWN DATE 5-10-61
CHECKED DATE
APPROVED DATE 5-12-61
DRAWING NUMBER 14363C


SCHEMATIC
MEGOHM BRIDGE
KEITHLEY INSTRUMENTS, INC.
CLEVELAND, OHIO
14522D
515
MODEL
NEXT ASSEM.
E ECO 1516 RER 10/15/62
D ECO 1508 RER 8/28/62
C ECO 1303 MF 1/26/62
B ECO 1247 CM 12-4-61
G ECO 2291
F ECO 2212
A - PRODUCTION
APPR.
NOTES:
1. * INDICATES ± 0.02% TOLERANCE
2. CAPACITANCE IN MICROFARADS EXCEPT WHERE OTHERWISE INDICATED
3. △ INDICATES NOMINAL VALUE
S-1 FUNCTION SWITCH
OPERATE
STANDARDIZE
CALIBRATE
EXTERNAL OPERATE
S-2 MULTIPLIER SWITCH
S-3 BRIDGE VOLTS
S-9 COARSE ZERO
DECK 1
DECK 3
COARSE ZERO CONTACT SEQUENCE
DECADE SWITCHES CONTACT SEQUENCE
X = SWITCH CLOSED
S-10 MV PER DIV. NULL DETECTOR
M-1 2.5 μA / DIV. ZERO CENTER
10 TURN FINE ZERO
S-11 PUSH TO READ
K-1 HIGH VOLTAGE RELAY
EXT. VOLTS J-3
J1 INPUT
J2 EXTERNAL INPUT
GUARD
DRIVEN GUARD
SAFETY SWITCH S 13
J-4 ACCESSORY OUTLET
P-1 POWER CORD
F-1 115V-0.25A 230V-0.125A
S-12
T-1
T-2
S-4 X100. ±0.05%
S-5 X10.
S-6 X1.
S-7 X.1
S-8 X.01 ±0.1%
X.001
V1
V2 6418
V3 6418
V4 OB2
DS 1
DS 2 6.3V. 0.2A

KEITHLEY INSTRUMENTS, INC.

INSTRUCTION MANUAL
CHANGE NOTICE
MODEL 515A MEGOHM BRIDGE

INTRODUCTION: Since Keithley Instruments is continually improving product performance and reliability, it is often necessary to make changes to Instruction Manuals to reflect these improvements. Also, errors in Instruction Manuals occasionally occur that require changes. Sometimes, due to printing lead time and shipping requirements, we can't get these changes immediately into printed Manuals. The following new change information is supplied as a supplement to this Manual in order to provide the user with the latest improvements and corrections in the shortest possible time. Many users will transfer this change information directly to a Manual to minimize user error. All changes or additions are underlined.

CHANGES:

(1) Page 26, Replaceable Parts, Resistors, Add the following resistor as follows:
R354, 100Ω, 10%, 1/2W, Comp, 01121, EB-100Ω, R1-100

(2) Page 21, Replaceable Parts, Diodes, Change D105, D106, D111, D112, D113, and D114 to read as follows:
D105, Not Used.
D106, Not Used.
D111, Not Used.
D112, Not Used.
D113, Zener, 15V, 1/4W, 12954, IN718, DZ-18
D114, Zener, 15V, 1/4W, 12954, IN718, DZ-18

(3) Page 22, Replaceable Parts, Resistors, Change R123, R124, R125, and R126 to read as follows:
R123, 845Ω, 1%, 1/2W, MtF, 07716, CEC-845Ω, R94-845
R124, Not Used
R125, Not Used
R126, 845Ω, 1%, 1/2W, MtF, 07716, CEC-845Ω, R94-845

(4) Page 22, Replaceable Parts, Transistors, Change Q101 and Q102 to read as follows:
Q101, Not Used
Q102, Not Used

28775 AURORA ROAD • CLEVELAND, OHIO 44139 • (216) 248-0400
TELEX: 98-5469 • CABLE: KEITHLEY

CHANGE NOTICE

July 17, 1969 MODEL 515 MEGOHM BRIDGE

Page 3-6. Change the last sentence in the first paragraph to read:

The chamber and the connecting cable are rated for continuous operation at temperatures as high as 125°C.

Page 6-7. Change to the following:

Circuit Desig.	Number	Mfg. Code	Keithley Part No.
V1	5886	80164	EV-5886-2X
V2	6418 or 592	80164	EV-CK6418 or EV-CK592-4
V3	6418 or 592	80164	EV-CK6418 or EV-CK592-4

Page 6-4. Change to the following:

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.
R107	$10^9\ \Omega$	0.5%, 1/R W	GCb	80164	---	20658A
R109	$10^{10}\ \Omega$	0.5%, 1/R W	GCb	80164	---	20659A
R109	$10^{11}\ \Omega$	0.5%, 1/R W	GCb	80164	---	20660A
R110	$10^{12}\ \Omega$	0.5%, 1/R W	GCb	80164	---	20661A